NORTHERN ARIZONA UNIVERSITY

ME476C SP25 – PIV Group

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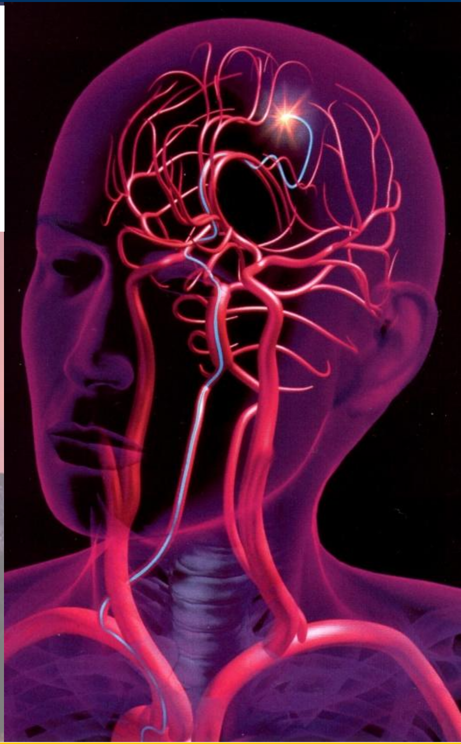
Development of a Novel Particle Image Velocimetry System for the NAU Bioengineering Devices Laboratory

Research Area: Translational research on biomaterials, flow modeling, and medical device development for the treatment of aneurysms



Particle Image Velocimetry (PIV):

A system that uses a combination of a laser and an ultra-high-speed camera to track the change in position of fluorescent tracer particles within a fluid flow, allowing the analysis of the velocity field within the fluid.

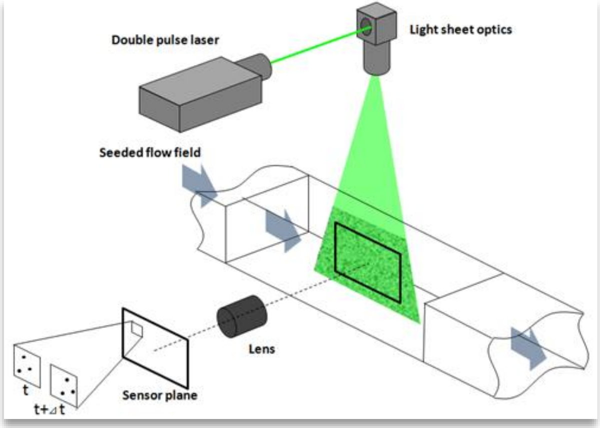


Figure 1 – Overview of Typical PIV System [1]

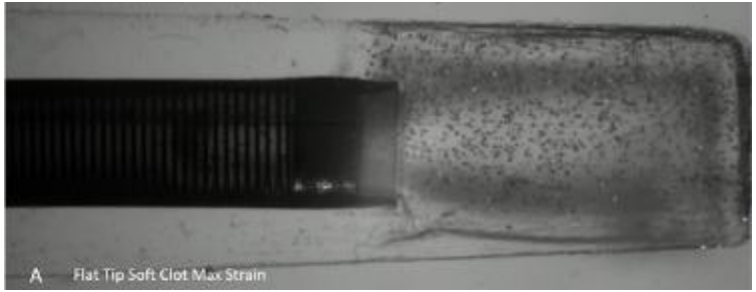
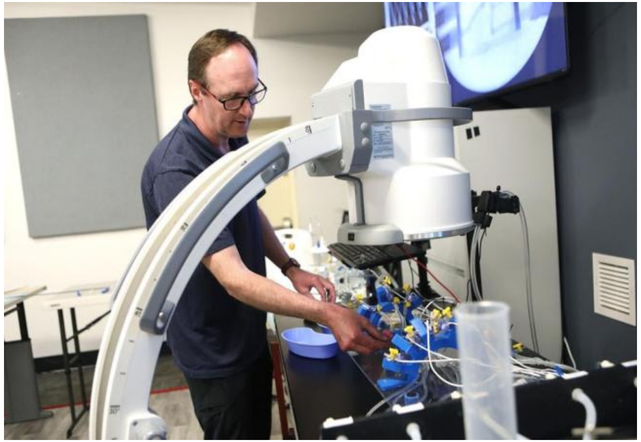


Figure 2 – Previous PIV study conducted by the BDL

Project Overview

Sponsor: Tim Becker, PhD
Associate Professor
Mechanical Engineering Department
Principle Investigator
Bioengineering Devices Laboratory (BDL)
Chief Technology Officer
Aneuvas Technologies, Inc. (ATI)

Client: Wyatt Clark, M.S.
PhD Candidate
Mechanical Engineering Department
Senior Research Associate
Bioengineering Devices Laboratory (BDL)



PROJECT JUSTIFICATION

- Stroke is the 2nd leading cause of death and a leading cause of disability worldwide [2].

- Ischemic Stroke: blood flow is blocked in the brain – treated with drugs or mechanical thrombectomy.

- Hemorrhagic Stroke: rupture of blood vessel in the brain – treated with coiling and stents.

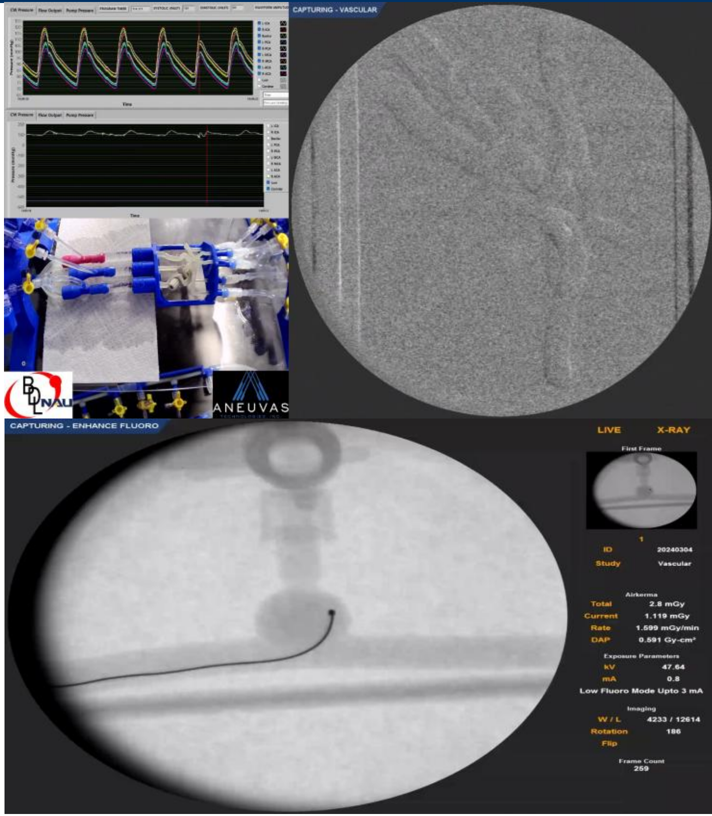


Fig. 3 - BDL aspiration thrombectomy study (top) BDL coiling study (bottom)

Background & Benchmarking

Three Benchmarking Setups:

- <u>Minimum Viable System</u>
  - Generic Function Generator, claimed 30MHz frequency
  - Laser from CNC Engraver
  - 200 Hz, 1.7MP Camera
  - **<u>Cost - $2,314</u>**
- <u>Middle-of-the-Road</u>
  - Tektronix 25MHz Function Generator
  - Pulsed Nanosecond Laser, 30mW, 523nm Wavelength
  - 1kHz, 1.3MP Camera
  - **<u>Cost - $7,373</u>**
- <u>Beyond Our Wildest Dreams</u>
  - 4.5kHz, 1MP Camera
  - Variable Pulsed Nanosecond Laser, Built to Order for PIV
  - Berkeley Nucleonics 50MHz, 8 Channel Function Generator
  - **<u>Cost - $56,400</u>**

Fig. 4 – Generic Engraver Laser

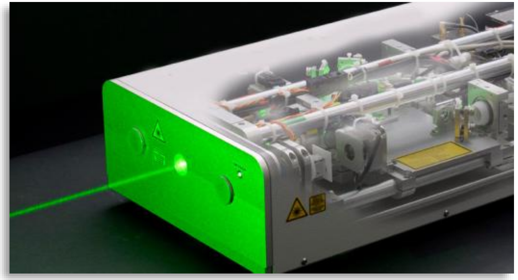


Fig. 5 – Litron LD-527 PIV Laser

Customer Requirements

- Ease of Setup
  - **How long to assemble? Is it portable? How intensive is the process?**
- Camera Resolution, Framerate, Runtime
  - **Better visuals of flow, with less motion blur and a longer time of recording.**
- Strength of Laser
  - **Important for tracer particle refractivity, but not powerful enough to wash out imagery.**
- Close to OSHA machine and laser guard standards
  - **Laser is powerful enough to cause serious damage to eyes, direct or through refraction.**
- Width of laser sheet is sufficient for particle density
  - **Important for uniform illumination of flow field.**
  - **Too narrow could not capture enough particles, while too wide could have poor contrast.**
- Use of a Multi-Function Generator
  - **Non-proprietary interface; reduces familiarization issues.**
  - **Controls the entire PIV setup (camera, laser, experimental conditions).**

Engineering Requirements

- Setup Time
  - **Must be relatively quick: ≤ 60 minutes.**
- Resolution, Camera framerate, Run Time
  - **Resolution needs to be high: Pixel area of ~2073600 (2 megapixels)**
  - **Framerate needs to capture fluid motion over time: ≤1000 FPS**
  - **High FR and Resolution lead to shorter run times: 10 seconds**
- Laser Power
  - **Range of power to cause refractivity without washing out image: 50-150mW**
- Laser Sheet Thickness
  - **How thick the laser sheet can be to pick up refraction:100-200 microns**
- Risk Assessment Score
  - **A score of 1 (poor) to 10 (safe) that rates the general safety of the PIV setup**
- Refractivity Index
  - **Appropriate RI limits distortion of flow measurements/imagery: RI of ~1.5**
- Frequency
  - **High frequency prevents motion blur for fast flows.**
  - **Accuracy of particle displacement for velocity equations.**
  - **~.9 nanoseconds.**

Quality Function Deployment Diagram

Table 1 – Quality Function Deployment Diagram Correlating Customer with Engineering Requirements

		Technical Requirements									Benchmarking		
Customer Needs	**Customer Weights (1-5)**	Setup Time	Sheet Thickness	Resolution	Camera FR	Run Time	Laser Power	Risk Assessment Score	Refractivity Index	Frequency	*Minimum Viable System*	*Middel of the Road*	*Beyond our Dreams*
Ease of setup	2	10					5				3	7	7
Camera Resolution	4										10	8	7
Camera Framerate	5			10	10					7	2	7	10
Camera Run Time	3			8	8	10					2	8	10
Strength of Laser	3						10	7			8	5	5
Close to OSHA machine and laser guard standards	1	4					6	10			0	10	10
Width of laser sheet is sufficient for particle density	3		10				4		3		_	_	_
Multi-function Generator	5	5			7					10	0	10	10
Technical Requirement Units		min	microns	Pixel Area	FPS	Seconds	mW	Score	RI	s			
Technical Requirement Targets		< 60	100-200	2073600	≤1000	10	50-150	TBD	~1.5	10^-9			

SOTA Literature Review

Main Topics:

- PIV Practical Guide [3]
- Applications of CFD [4]
- Edmund Optics [5]
- Phantom Manufacturing Techniques and Cost [6]
  - Resin Printing vs Traditional Casting
- Optical Studies for Spherical Lenses [7]
- Biological Studies [8]
  - Circle of Willis

Engineering Analysis – Particle Density

$$PD = \frac{n_{particles} * A_{particle}}{A_{phantom}} \quad (1)$$

$$m_{particles} = \frac{n_{particles}}{p_{particles}} \quad (2)$$

$PD - Particle\ Density\ (\%)$

$n_{particles} - Number\ of\ Particles$

$A_{particle} - Area\ of\ particle\ (cm^2)$

$A_{phantom} - Area\ of\ phantom\ in\ viewing\ window\ (cm^2)$

$m_{particle} - Mass\ of\ particles\ (g)$

$p_{particles} - Density\ of\ particles\ (\frac{g}{cm^3})$

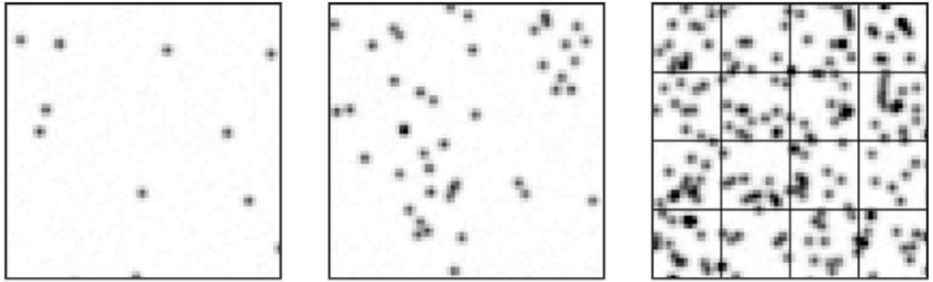


Figure 6: Examples of different particle densities [9]

Engineering Analysis – Reynolds Number for Neurovascular Blood Flow

- $Re = \frac{(\rho u D)}{\mu}$ **(At 37 degrees Celsius)** **(3)**

  ρ is the density of blood (typically about 1060 kg/m^3) [10].

  u is the average blood velocity through the Basilar artery (.55m/s) [11].

  D is the diameter of the blood vessel (1.83E-3m or 1.83mm) [12].

  μ (mu) is the dynamic viscosity of blood (2.78E-3 Pa*S or 2.78mPa*S) [13].

- **Re = (1060*.55*1.83E-3)/(2.78E-3) = <u>383.77</u>** **(4)**
- While the exact bounds are unknown for blood flow, **this number suggests a healthy/normal (laminar) blood flow through the Basilar artery**

Engineering Analysis – Phantom Manufacturing Cost

$$PPU = (C_F/n) + C_v + t(C_L) \quad (5)$$

PPU – Price per unit
C_F – Fixed Costs
n – Quantity
C_v – Variable Costs
t – Labor Time (hours)
C_L – Hourly Labor Cost

Table 2 – PPU for Each Method for Quantities Between 1-200

Quantity	Traditional Method	Outsourced SLA	In-house SLA
1	$ 413.75	$ 201.25	$ 2,649.60
5	$ 188.75	$ 136.25	$ 584.60
10	$ 160.63	$ 128.13	$ 326.48
20	$ 146.56	$ 124.06	$ 197.41
25	$ 143.75	$ 123.25	$ 171.60
50	$ 138.13	$ 121.63	$ 119.98
100	$ 135.31	$ 120.81	$ 94.16
150	$ 134.38	$ 120.54	$ 85.56
200	$ 133.91	$ 120.41	$ 81.26

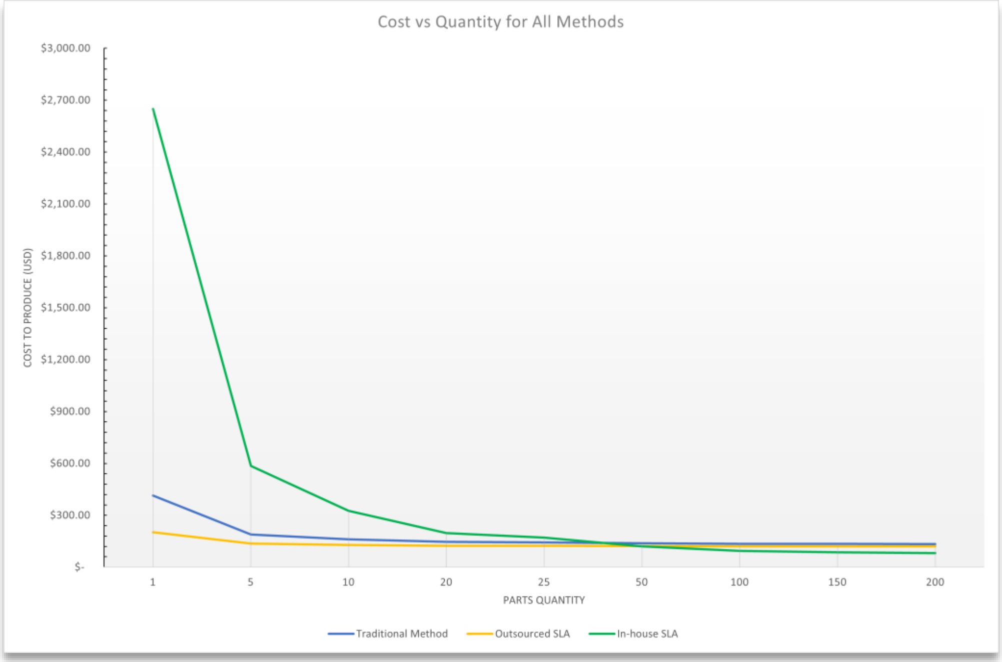


Fig. 7 – PPU for Each Method as Quantity Increases

Engineering Analysis – Laser Sheet

$$w_f = \frac{\lambda f}{\pi w_o} = \frac{(532\times10^{-9})m(250\times10^{-3})m}{\pi(42.3691\times10^{-6})rad} \approx 0.99\ mm \quad (6)$$

- λ = wavelength of laser beam
- f = focal length of converging beams
- w_o = beam waist
- w_f = half of beam thickness

$$w_o = \frac{\lambda}{\pi\theta} = \frac{532\ nm}{\pi(3.9968)} \approx 42.3691\ \mu m \quad (7)$$

$$T_{sh} = 2w_f = 2(0.99) \approx 2\ mm \quad (8)$$

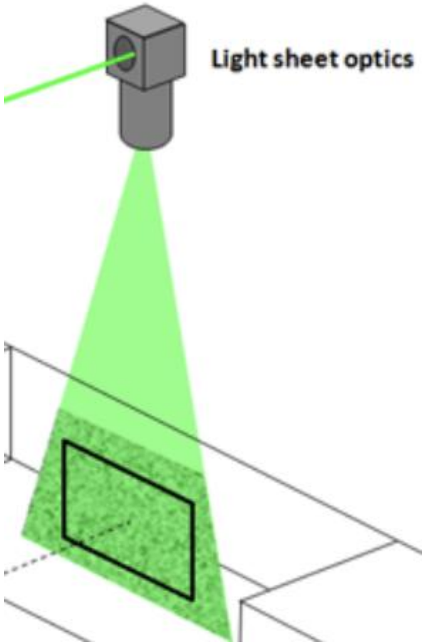
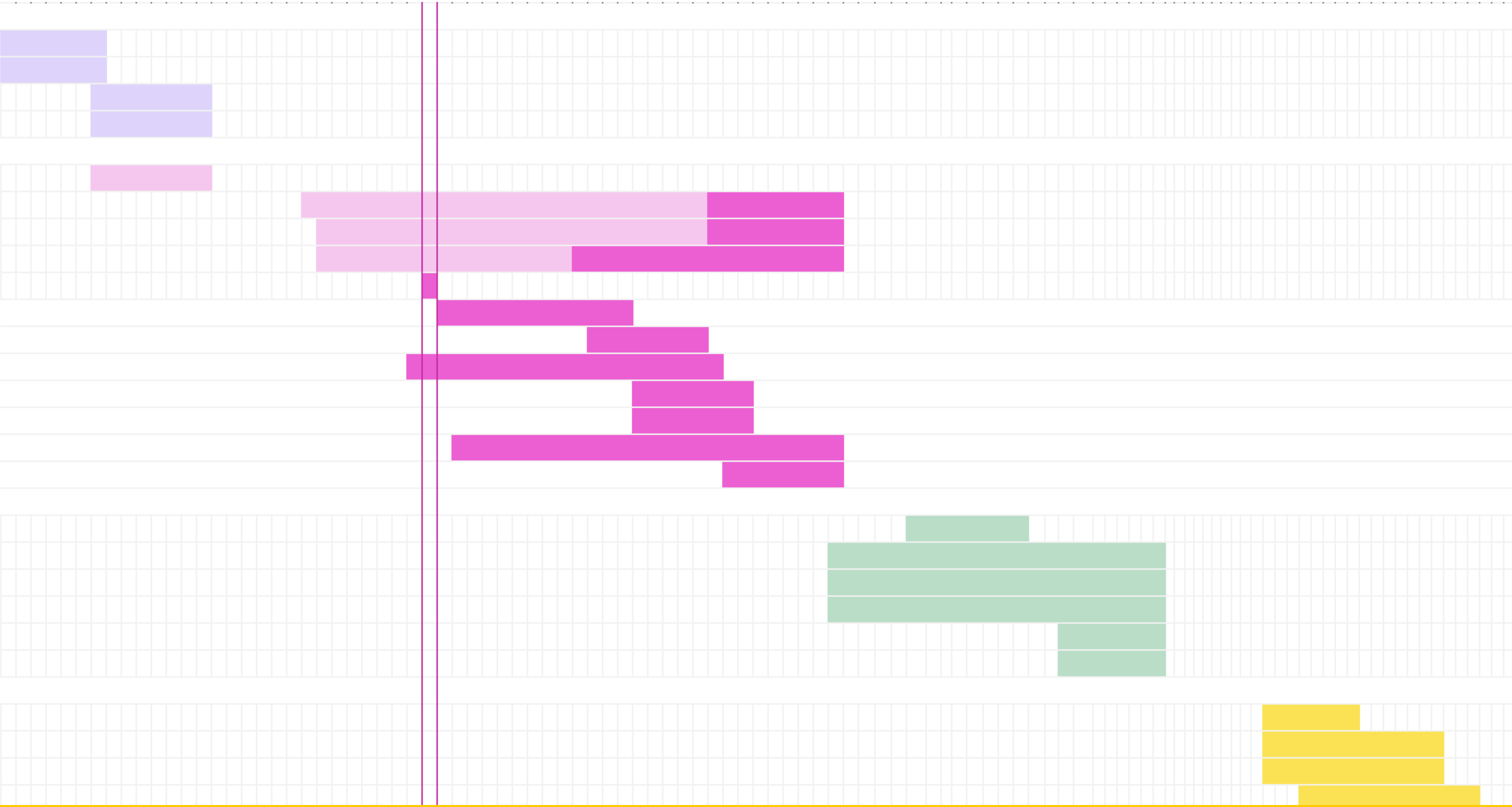


Fig. 8 – Light Sheet Detail View [1]

Project Schedule

Phase 1				
HW 0	All	100%	1/13/25	1/19/25
HW 1	All	100%	1/13/25	1/19/25
Team Charter	All	100%	1/19/25	1/26/25
HW2	All	100%	1/19/25	1/26/25
Phase 2				
HW 2	All	100%	1/19/25	1/26/25
Lit Review	All	75%	2/2/25	3/9/25
Benchmarking	All	75%	2/3/25	3/9/25
Begin Engineering Analysis	All	50%	2/3/25	3/9/25
Presentation 1	All	0%	2/10/25	2/10/25
Concept Generation	All	0%	2/11/25	2/23/25
HW 3	All	0%	2/21/25	2/28/25
Grant Application	All	0%	2/9/25	3/1/25
Concept Selection	All	0%	2/24/25	3/3/25
Presentation 2	All	0%	2/24/25	3/3/25
Website	Santiago	0%	2/12/25	3/9/25
Report 1	All	0%	3/2/25	3/9/25
Phase 3				
Analysis Memo	All	0%	3/14/25	3/21/25
Finalize Design	All	0%	3/9/25	3/31/25
1st Prototype	All	0%	3/9/25	3/31/25
CAD	All	0%	3/9/25	3/31/25
Fall Schedule	Chris	0%	3/24/25	3/31/25
3rd Presentation	All	0%	3/24/25	3/31/25
Phase 4				
Report 2	All	0%	4/11/25	4/18/25
HW 4	All	0%	4/11/25	4/25/25
Final CAD and Final BOM	All	0%	4/11/25	4/25/25
2nd Prototype	All	0%	4/14/25	4/28/25



Budget and Plan

Overall Project Budget: $18,300

Design and Manufacture: $3,000

Critical Equipment: $15,000

Group Fundraising: $300 (Min.) - $2,000 (Expected Max)

Planned Expenditure for SP25

Purchase of all Critical Equipment: -$15,000

Prototyping: -$1,000

Discretionary: -$1,000

Final Budget Remaining at EOS: $1,300

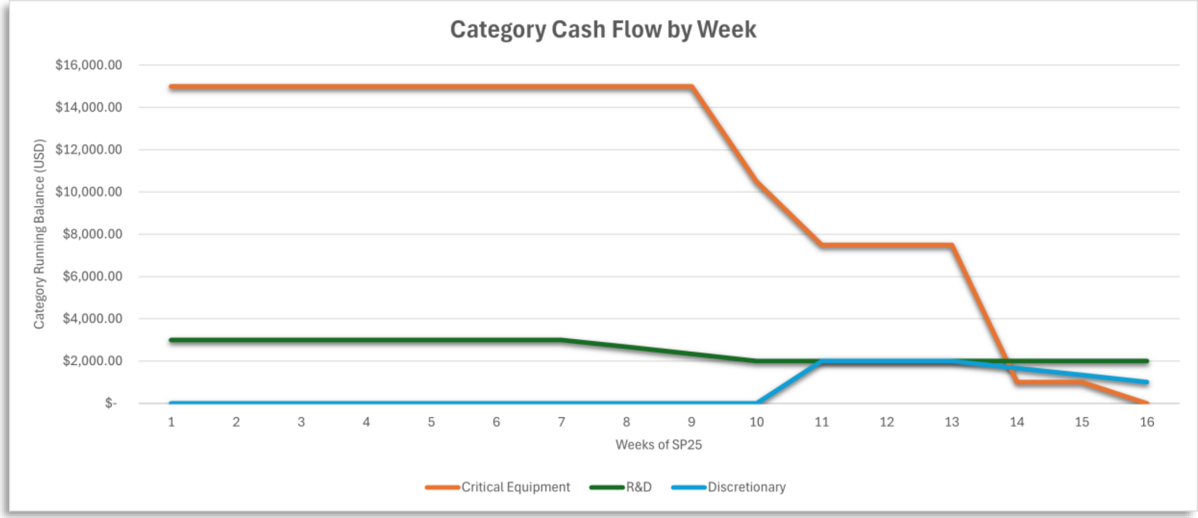


Fig. 9 – Running Budget Balance for Each Expenditure Category by Week of Semester

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THANK YOU!

QUESTIONS?

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